



Fermi National Accelerator Laboratory

FERMILAB-Conf-97/240-T

Extracting α_s from Tevatron Data

Walter T. Giele

*Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510*

July 1997

Published Proceedings of the *5th International Workshop on Deep Inelastic Scattering and QCD*,
Chicago, Illinois, April 1997

Disclaimer

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Distribution

Approved for public release; further dissemination unlimited.

Extracting α_S from TEVATRON data ¹

Walter T. Giele

*Fermi National Accelerator Laboratory, P. O. Box 500,
Batavia, IL 60510, U.S.A.*

July 1997

Abstract

In this contribution we explore one of the many possibilities of determining the strong coupling constant α_S at hadron colliders. The method considered is quite unique compared to other methods in that the value of α_S is determined by the “evolution rate” of the parton density functions rather than by the “event rate”.

¹Talk given at the “5th International Workshop on Deep Inelastic Scattering and QCD”, Chicago, April 1997.

Introduction and Motivation

Hadron colliders will supply an increasing amount of data with the upcoming high luminosity TEVATRON run and the LHC project. Methods for extracting α_S and parton density functions from these data sets can therefore expect a steady improvement in the precision over the coming decades.

Often it is claimed that hadron colliders cannot do such precision measurements. A few comments can be made in answer to this. First of all, a hadron collider measures the value of α_S at many different values of the (partonic) center of mass energy. This is in contrast to e^+e^- -colliders where the center of mass energy is fixed. In fact, at the TEVATRON the partonic center of mass energy useful for the α_S -extraction can go as high as 1 TeV (and at the LHC this will increase by an order of magnitude). Secondly, a hadron collider can make accurate measurements by selecting appropriate observables. For this purpose we select in this talk the *normalized* one jet inclusive transverse energy distribution. The value of α_S will be determined from the shape of the distribution. The major factor determining the shape is the fraction of quarks in the colliding hadrons. Due to the evolution of the parton density functions the quark fraction at moderate parton fractions decreases as the jet energy increases. This depletion is controlled by the strength of the strong coupling constant.

Because we look at a normalized quantity both the theoretical (renormalization scale dependence) and experimental uncertainties (e.g. luminosity uncertainty) are much smaller than one would expect.

Measurement and Methodology

As mentioned in the introduction, the observable used is the normalized one jet inclusive transverse energy distribution. As an example we use the published run 1a results from the CDF collaboration [1]. For the theoretical prediction we use the JETRAD monte carlo [2] with the cuts and jet algorithm as close as possible to the experimental setup. The MRSA' parton density functions [3], which allows varying α_S , were used. The renormalization/factorization scale, μ , was chosen to be a constant, λ , times the maximum jet transverse energy, E_T , in the event. Both data and theory are divided by the "reference" theory prediction which is given by: $\alpha_S(M_Z) = 0.120$, $\mu = E_T$. To normalize the distribution we choose the ratio to be equal to unity at $E_T = 200$ GeV .

We show the α_S -dependence in fig. 1a and the scale dependence in fig 1b. As can be seen the dependence on α_S is quite substantial compared to both the experimental and theoretical uncertainties. Also note that the leading order (LO) and next-to-leading order (NLO) results are quite close. The only difference between the two predictions is the (expected) reduced scale dependence at NLO. The method to extract α_S is now quite simple: we minimize the χ^2 to fit the theory to the data in fig. 1 between $30 \text{ GeV} \leq E_T \leq 200 \text{ GeV}$ by

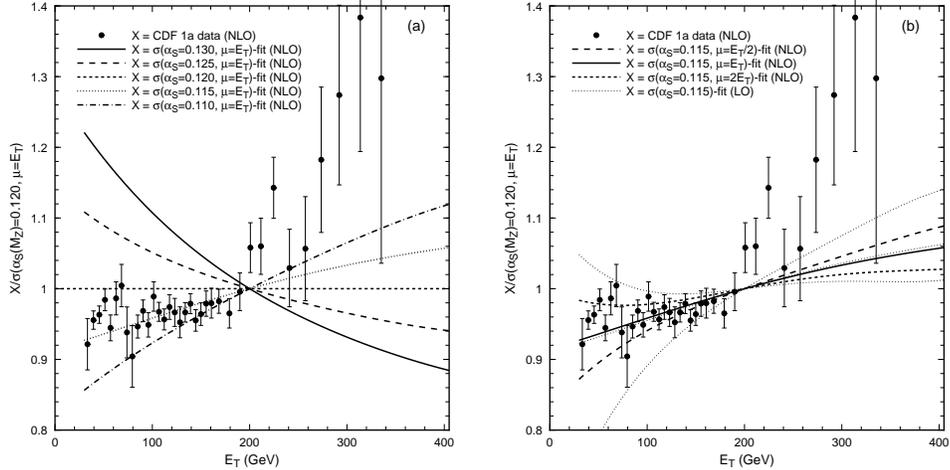


Figure 1: (a) The sensitivity of the distribution to the value of $\alpha_S(M_Z)$. For comparison the CDF data [1] is also shown. (b) The scale dependence of both the leading (LO) and next-to-leading (NLO) predictions.

varying both α_S and λ . The results and, more importantly, the interpretation are discussed in the next section. Note that we do not consider the systematic uncertainties at this point. They can be easily included in the χ^2 -fit by building up the correlation matrix out of the systematic uncertainties [4]. Their inclusion is better left to the experimenters. Here we want to concentrate on the methodology.

Interpretation and Results

In fig. 2a we show the results of the minimization procedure to fit to the data. Both the minimum and the $1-\sigma$ uncertainty ellipse is shown. The figure contains all the information we can extract from the data. While the central value is quite trivial to determine, the interpretation of the uncertainty is not. The perfect answer (that is no renormalization scale uncertainty) would be a vertical strip. The uncertainty would then simply be the width of the strip independent of the choice of λ . However, in fixed order perturbative QCD we have a residual scale sensitivity due to the truncation of the series. This is reflected in the slope of the ellipse-axis. In fact one could argue that the slope is the correct measure of the theoretical uncertainty. When comparing results from different experiments this slope could be used to weight different experiments on their theoretical uncertainty. This all implies that the parameter λ cannot be

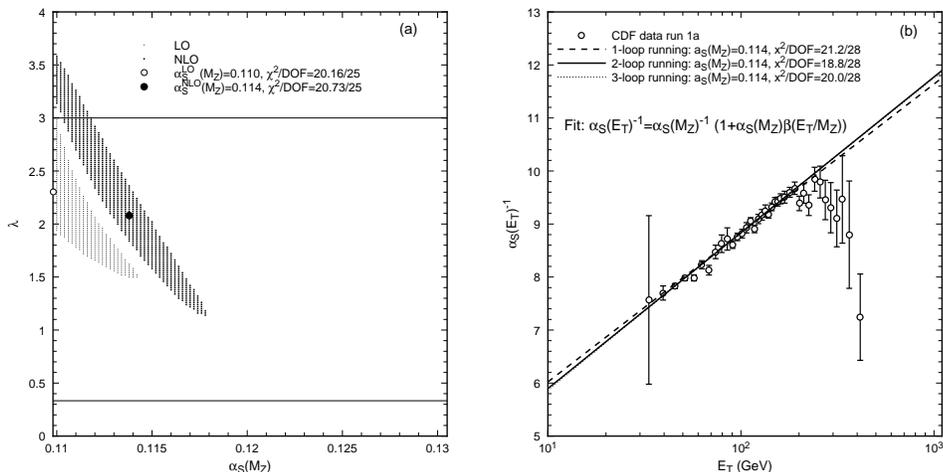


Figure 2: (a) The result of the χ^2 -fit to the data for both the LO and NLO predictions as the minimum and the $1\text{-}\sigma$ uncertainty ellipse. (b) A comparison of the extracted central value of $\alpha_S^{NLO}(M_Z)$ with its one- two- and three-loop evolution compared to $\alpha_S(E_T)$ extracted from the data using the method of ref. [6].

considered a fitting parameter as α_S is, nor is it in a direct manner related to the theoretical uncertainty. Note that when the data accuracy increases (e.g. the CDF/D0 run 1b data) the fit of the theory to the data will become more strained and the variation of λ will become more constrained. This does not indicate that the theoretical uncertainty is decreasing. On the contrary, this means that the NLO prediction is becoming more and more inadequate to describe the data and even higher order calculations are needed.

For the moment we use a naive procedure to quote the theoretical uncertainty. The experimental uncertainty is taken to be the width of the ellipse at the minimum, while the theoretical uncertainty is taken as the variation within $1\text{-}\sigma$ for scales between $1/3 \leq \lambda \leq 3$. The results are

$$\begin{aligned}\alpha_S^{LO}(M_Z) &= 0.110 \pm 0.001(\text{stat}) \pm 0.004(\text{theory}) \\ \alpha_S^{NLO}(M_Z) &= 0.114 \pm 0.001(\text{stat}) \pm 0.004(\text{theory}) .\end{aligned}$$

Alternatively, one could argue that the difference between the LO and NLO value of α_S should be larger than the difference between the NLO and NNLO value of α_S , giving an alternative, but equal, estimate on the theoretical uncertainty of 0.004.

Conclusions and Outlook

We have used the normalized one jet inclusive transverse energy distribution to extract $\alpha_S(M_Z)$. The fact that we used the normalized distribution reduces the experimental and theoretical uncertainty significantly. To improve the results we need to fit the parton density functions (specifically the gluon) together with the value of α_S . This should remedy the obvious discrepancies between the data and theory for $E_T > 200$ GeV (see ref. [5]). Such a measurement would not only give us α_S , but simultaneously a *true* NLO determination of the gluon parton density function. In fig. 2b we finally show, as a cross check, the comparison between the α_S extracted in this talk and the α_S -values determined in each E_T -bin, obtained using the methods of ref. [6] (incorporating parton density functions with varying α_S). As can be seen the agreement between the two methods is quite good.

The new run 1b data from the CDF and D0 collaboration will severely test the NLO description of the data and higher order calculations might be needed to describe these results and extract the gluon parton density function and α_S .

References

- [1] F. Abe et al., *Phys. Rev. Lett.* **77** 438 (1996).
- [2] W. T. Giele et al., *Nucl. Phys.* **B403** 633 (1993).
- [3] A. D. Martin et al., *Phys. Lett.* **B387** 41 (1996).
- [4] See e.g. S. Alekhin, *hep-ph* 9611213 (1996).
- [5] J. Huston et al., *Phys. Rev. Lett.* **77** 444 (1996).
- [6] W. T. Giele et al., *Phys. Rev.* **D53** 120 (1996).